Episode 20:

What we learned from the American Astronomical Society

Fraser Cain: Astronomy Cast episode 20 for Monday January 22, 2007: What we learned from the American Astronomical Society

Welcome to Astronomy Cast your weekly facts based journey through the cosmos, where we help you understand not only what we know, but how we know what we know. My name is Fraser Cain, the publisher of The Universe Today, and with me is Dr. Pamela Gay, a professor at Southern Illinois University Edwardsville. Hi, Pamela.

Dr. Pamela Gay: Hey Fraser

Fraser: We've been sort of leading up to this, we've mentioned that we're going to do it, and now I think that we're ready. So, I think we're going to be able to let people hear some of the interviews you did at the American Astronomical Society.

Pamela: That sounds like a great plan. I was able to talk to some really great people and learn about some areas of science that my own research never even touches on, and find out about things that are actually invalidating parts of the textbook I teach out of. It's always fun to be able to turn to my students and say 'Today I found out that your textbook is currently out of date."

Fraser: I think we've covered a lot of subjects, you know – from supernova, dark matter, dark energy – and this is all the latest stuff. I'm hoping that people have heard all the episodes, they'll be able to put it all into context and go "oh okay, I understand now from this point of view." I think all of the stuff we'll be talking about today, we've actually covered the basics in previous shows.

Pamela: And now we get to update and invalidate ourselves all at the same time.

Fraser: Perfect. So we're incorrect, out of date. So what's first?

Pamela: Well, the very first, really cool press conference at the meeting had a group from the COSMOS survey. COSMOS in this case is actually an acronym, for the Cosmic Evolution Survey. They used a bunch of telescopes – Hubble, XMM Newton, Spitzer, Keck, the Very Large Telescope in Chile, the Very Large Radio Telescope Array in New Mexico, and the Subaru telescope - just about every telescope on the planet it seemed like – to in detail measure the distribution of matter that we can see (luminous matter) and the distribution of dark matter. They had some really cool results that I was able to get Richard Massey, a post-doc in the project to describe straight for our listeners.

Fraser: All right, let's hear what he has to say.

Dr. Richard Massey: So what we've revealed in our map of the dark matter distribution is that it makes a filamentary structure, rather like a sponge. All the dark matter is distributed along a series of very long filaments, which meet in massive clumps of dark matter and surround enormous voids in space. This is absolutely vital in terms of the baryonic or ordinary matter, and helping it evolve into the forms we se around ourselves today.

It's vital in two ways. Firstly, the sheer amount of the stuff holds the universe together as it tries to expand away from the big bang. By its own gravity, it keeps everything compact and in places where it can go on to form galaxies and stars.

As a second point, the dark matter is also vital because it has a crucial lead-time over the ordinary matter in its gravitational collapse. From a smooth universe, at the big bang, which we see in the cosmic microwave background, this gradually transmissions into a more clumpy, filamentary distribution where the matter is more compactly represented in space.

So the dark matter, which begins this collapse first, therefore forms an underlying scaffold, which is absolutely vital for the baryonic matter, which can later flow into this scaffolding. It's very much like scaffolding, as you would build a house. The dark matter goes up first, around the outside, and then the baryons, which we know and understand, later flow into that scaffolding and are slowly, gradually, constructed into the galaxies, stars and planets that we find around ourselves today.

Pamela: Can you tell us anything about – are the peaks the same between the baryonic and dark matter or are there offsets? What new things have we learned about the distribution?

Dr. Richard Massey: So generally the distribution of the dark matter and baryonic matter are very strongly correlated. In other words where there's dark matter, in general, there's some baryonic matter. That's very much in line with the theoretical expectations that were made in advance of this new math. So overall it really provides a very strong confirmation of those theories, that we really understand what's going on, on large scales.

Having said that, there are a couple of discrepancies in the distribution of baryons and dark matter, so in some places there is dark matter and no baryons, and in others vice versa. Although fundamentally this map is really at the limits of image analysis techniques, it's really pushing the bounds of what we're able to measure, so it's slightly noisy. However, these (and I don't necessarily want to believe all of these discrepancies) offer really tantalizing glimpse into differences of behaviour of dark matter and normal matter that may provide a clue as to its nature.

So the first question we've answered is where it is. Answering what it is, these discrepancies might provide some insights by the different ways that they interact with each other and consequently the different places that they end up.

Pamela: Does this completely rule out, forever, the fact that gravity might have some additional modified term, or are you simply saying there has to be dark matter but gravity can still be modified?

Dr. Richard Massey: So this result, and others like it using this technique of gravitational lensing, now provide mounting evidence that there is definitely some sort of dark matter in the universe, some additional missing mass over the baryons that we can interact with, that we can see, breathe, feel and touch around us. There is definitely something else there.

Now, of course, this doesn't rule out the fact that there might be other theories of gravity that might also be true. So, these initial theories were brought in to explain theories mounting evident a couple of decades ago that there is missing matter in the universe. Now people suppose that either there is missing matter (and that therefore some of it is made up by dark matter), or perhaps that the theories of gravity are wrong. We have found that there is definitely missing mass, and definitely dark matter, but this doesn't say anything necessarily about the possibility that there might be both.

Fraser: Well, that was great! Good job on getting that interview! So what's the next piece of research that you were able to look into?

Pamela: Well, a little bit later in the conference they had basically what turned into a supernova round up of great explosive discoveries in our universe.

Dr. Stephen P. Reynolds from North Carolina State University presented on a supernova remnant that is near and dear to a lot of people: the Kepler supernova remnant. This is a large nebula that can be seen that was formed in an explosion that was observed by THE Kepler, the Kepler who figured out how planets move and all that sort of neat stuff. In studying this supernova, he found that our understanding of when the elements needed to form planets were released into the universe may be wrong, and our understanding of exactly what types of stars can become white dwarfs may also be wrong. He took the time to sit down and explain all of his research and all of its repercussions to our understanding right for our listeners.

Fraser: All right, well let's listen to this one!

Pamela: I'm here with Stephen Reynolds, a professor of physics at North Carolina State University. This morning he did a wonderful presentation on how type Ia supernovas aren't exactly everything we ever thought they were. Could you sum up your results for us?

Dr. Stephen Reynolds: Short answer is that the nearest supernova well observed from Earth in 1604 has left a remnant which seems to have characteristics of both a type Ia supernovae exploding white dwarfs and the single massive stars that leave their surroundings full of dense circumstellar material. Kepler's supernova remnant appears to be a type Ia supernova that also left behind lots of stuff, indicating perhaps that it's progenitor was perhaps more massive than the common, run-of-the-mill type Ia supernova.

Pamela: Now, this is a supernova that people have clearly known about since, well, Kepler was around. Why is it that it has taken so long for forensic astronomy to make a clear determination on the type of supernova that created this object?

Dr. Stephen Reynolds: It's useful to remember first that the whole idea of supernovae is only about 80 years old. The idea of type I and type II is about 50 years old. The realization that type I's were partly massive stars that had lost their hydrogen and partly exploding white dwarfs is only about 20 years old. So it's truly only been a puzzle for about 20-25 years. It's x-ray astronomy that helps you make the distinction and we've only had x-ray astronomy as well for about that long.

After that, why didn't we face up to it sooner? Well, it took a while to accumulate optical, x-ray and other kinds of information, so it's probably been a puzzle for about 10 years. The reason we didn't settle it sooner is because, well, scientists are conservative and most type Ia's don't seem to show this circumstellar material and so the conventional wisdom was if either it didn't have it, or if it had it, it wasn't a type Ia. So we've just been forced by the data to say, yes, it is a Ia.

Pamela: What were the lines of evidence that you used to clearly state, forever and always (we hope), that this is a type Ia supernova remnant?

Dr. Stephen Reynolds: We're very fortunate. An exploding massive star cooks lots of elements, but the densest ones wind up trapped in the neutron star left behind. The material that's ejected into space tends to have pretty well agreed upon patterns of heavy elements, for instance lots of oxygen and some iron (but not very much), whereas the exploding white dwarfs produce mostly iron, so that the ratio of oxygen to iron atoms is less than 1 for a type Ia. For a core collapse supernova, that ratio is predicted to be 70. Even astronomers should be able to tell the difference between 0.7 and 70, so that's what we did. We looked for the oxygen, which we couldn't find, we looked for the iron which was everywhere.

Pamela: Type Ia supernova – they're one of our standard candles that we use to measure the universe. If they aren't all exactly the same, what sort of evidence can we look for/inspect for to say that the ones we're using as standard candles are still trustworthy standard candles even though we have these other type Ia things that are slightly different?

Dr. Stephen Reynolds: Well, two answers to that. First one: the reason that Ia's have suddenly become so useful is because people realized that they weren't quite exactly the same –this was already realized. Purely observationally it was found starting in the early 90s, that the ones that were slightly brighter also lasted slightly longer - their light faded a little more slowly. Nobody knew why this was, exactly, they had some ideas but observationally, the brighter the slower, the faster the slightly dimmer. People were able to use that to correct a little bit, and it's that extra correction that gave us the leverage to learn the wonderful things that we've learned.

Now we don't know yet whether the actual explosion of a white dwarf that it originated from a more massive progenitor would be different, and if it obeyed this same relation – if it was brighter but also slower decaying then it's already taken care of. What would scare us is if it turned out to be radically different – that it was brighter but its decay rate mimicked a fainter one. Then we would really be in trouble because these would be the first type Ia's that the universe could produce, because their progenitors evolve faster and what you really don't want is a systematic effect with distance, so that the ones that seem to be furthest away that occurred the earliest are systematically different in a way that mimics a different kind of supernova.

What we're asserting is that the progenitor of that white dwarf, rather than being a star with maybe 2 solar masses, which could take a billion years from its birth to producing a white dwarf, might have had 6 or 7 solar masses – still not enough to become a core collapse supernova but enough to have evolved considerably faster and it would have to lose all that extra material (which we think happens), and that would be surrounding it. The white dwarf is still only 1.4 plus one atom mass, but its progenitor was more massive and rapidly evolving.

So basically, this is early days in this. We don't know whether we're learning about the mechanism for all Ia's and we just happen to have a system that is able to show us that better or if the explosion itself is characteristically different. We hope that if we find it's different, we will also find an imprint so that when we observe actual supernovae in distant galaxies, we'll say 'aha, this is one of these massive guys, we'll leave it out of the sample' we don't know yet what that signature might be or even if we'll need one.

Pamela: So what are you hoping to find to use to build on these results – perhaps some new explosions and what data do you need to better secure your result?

Dr. Stephen Reynolds: The first thing is, we have barely scratched the surface with this astonishing Kepler data set. We have 30 million x-ray photons each polished and cherished and focused to within a half-arc second by the splendid Chandra telescope, each of whose energy has been measured. We will be working for years just on analyzing Kepler's data and bringing it closer to the predictions of models.

Pamela: Well thank you very much Dr. Reynolds. Any parting words that you want to pass on to our audience?

Dr. Stephen Reynolds: Let me take the opportunity to point out one additional important feature of this. We live on a planet which is largely iron. It would be interesting to know how soon the universe could make iron. If a significant number of type Ia supernovae can live their lives out and explode in 100 million rather than 1 billion years, the universe started making heavy elements that could turn into planets and people ten times sooner than we thought. Next time you see a little green man, he might be older than you'd conceived.

Fraser: Great, alright – well that was good. Two down, what's the third one?

Pamela: Well, in that same press conference, Dr. Nathan Smith, a post-doc at the University of California, Berkeley, reported on these little blue stars (that in all reality are giant blue variables), that have nebula around them that looks suspiciously identical to the nebula that we find around the supernova remnant 1987a. He found that these blue stars, which we didn't think were likely to go supernova, just might be likely to go supernova. He talked to us about what this means to our understanding of stellar evolution.

Fraser: 1987a is the one that went off in the Magellan clouds, back in the---

Pamela: --Uh, Magellenic clouds

Fraser: Magellenic, right, sorry

Pamela: Named after Magellan, the explorer. Yeah, and it was the first supernova that we were able to get really good images prior to the supernova entirely by accident. We were imaging these nearby galaxies because they're nearby and easy to study, and this supernova went off, so we had all these images to go back and study what the star looked like right before the supernova. We built all these Rube Goldberg experiment-type theories to try and figure out how this star went supernova because it wasn't something we expected to explode. This new research by Dr. Smith and collaborators shows that maybe our initial understanding was wrong and maybe more stars than we ever imagined are capable of just exploding.

Fraser: Don't give everything away – let's hear what he has to say!

Pamela: Okay, here goes.

I'm here with Nathan Smith, a post-doc at the university of California Berkeley. He has some fascinating results that may just change our view of how giant stars end their lives, and may have some implications on Eta Carinae. So could you sum up your results for us?

Dr. Nathan Smith: What we've done is we've discovered a few new stars with circumstellar nebulae around them. This is material that is ejected before the star explodes and these nebulae look very similar to 1987a in terms of their geometry. They have a bi-polar geometry where they're ejecting material out of their poles but they also have an equatorial ring – a very prominent ring – and the similarity of these nebulae to the nebula that was around supernova 1987a has important implications about what that star might have been doing before it exploded. In particular it draws into question one of the prevailing models for how the 1987a circumstellar nebula might have formed and what that star might have been doing before it exploded.

Pamela: Can you tell us a little bit about what made 1987a such a unique and exciting case especially because it was so close?

Dr. Nathan Smith: Right, it was the nearest supernova in about 400 years that had been well observed. This wonderful data that we were able to obtain for 1987a showed more detail and it was the best-observed supernova ever. What we've learned from that is that we have data that existed before the supernova went off, and this had never been seen before with any kind of supernova. Astronomers were able to identify the star in images before it exploded that were taken a decade before. It was found that it was a blue supergiant, which contradicted most of the common wisdom at the time that a star should reach the stage of a red supergiant and then explode.

Pamela: Now, as some of our listeners may remember, in an earlier episode we discussed how supernovae come to happen. We discussed that stars like Eta Carinae end their lives as these giant stars that suddenly start blowing off these really hot winds as a Wolf-Rayet star and then they finally basically explode in their final death throes. Now, this was a star that under normal models would have gone through that phase, but now you're saying that they're basically exploding much earlier and not going through that phase. What implications does this have on our understanding of stellar evolution for these giant stars?

Dr. Nathan Smith: These other objects we've discovered are – at least one of them is known to be a luminous blue variable and the other ones may be going through a phase that is analogous to it.

First of all the nebula that are ejected are formed during this LBV phase and must be formed in a different way than had been proposed for supernova 1987a, which required transition through a red supergiant phase to a blue supergiant. It had to involve a merger to spin up the star to create this kind of geometry. Now we're seeing these other stars do that without this mechanism, without a merger, without passing through a red supergiant phase. The similarity of their nebulae to 1987a suggests that they may also be poised to explode; they might be in the final throes of their life. That suggests that we could be looking to these stars, the luminous blue variables, as possible progenitors of supernovae and the reason that is something new is because when we study the chemical abundances of the nebulae around LBVs and we think about their place in stellar evolution which is supposed to be at the end of core-hydrogen burning (which is the first stage of burning), and not yet at the more advanced stages which are required before the star can suffer a core-collapse. This means that if they do potentially explode that means that they're blowing up much sooner than we thought.

Pamela: Does this imply that the opportunity that someone alive today just might observe a supernova in the nearby universe has now gone up?

Dr. Nathan Smith: You mean for Eta Carina? I'm certainly hoping so at that. I'm planning on that one exploding near the end of my career.

[laughter]

Pamela: So we no longer have to wait for Eta Carina to become a Wolf-Rayet star, it just might go. Now these other stars that you're observing, are they also in the "they just might go" category?

Dr. Nathan Smith: The thing is we just don't know. The evolution of these massive stars is still very uncertain because they span a wide range of masses and are very rare, so we only have a few examples with which to try and piece together the complete picture and it's very difficult.

It doesn't just depend on the initial mass, it also depends on the rotation rate, it depends on the chemical abundances when the star was born, and it can depend on whether or not there was a companion star. All these variables figure into the equation in different ways. It may be the case that even two stars that start in life with the same mass, because of these other properties – different rotation rates, chemical abundances – might have end phases that are different. In other words a star with the initial mass that would normally reach a Wolf-Rayet phase after the luminous blue variable phase may not get there. So two stars in the same place in the H-R Diagram (which tells us about stellar evolution), two stars that look the same, one might blow and the other one might have to wait another 100,000 years.

Pamela: With all these things you're finding with these very surprising objects, what is the thing that has startled you the most in this discovery?

Dr. Nathan Smith: I guess it's the variety of the different possible end states of these stars. It's so phenomenally complicated, or it at least seems that way maybe because there are so few examples. As we continue to study these objects, we get more and more examples of them.

In another part that's related to that, the variety maybe comes by how fast transition has happened. For Eta Carina for example, when we've looked at the chemical abundances of material further away from the star, we see that the chemical abundances have changed. The pattern of the chemical abundances that have been ejected in the last 1,000 years have gone from normal composition like our sun to something that is very enriched in Nitrogen, so these things can change very fast. It's giving us clues that maybe the normal pictures of slowly transitioning from one stage to the next are not the norm, but maybe the episodic mass ejections may be more than the norm.

Pamela: Thanks a lot for spending the time talking to us, Nathan. Do you have anything that, in summary, you'd like to say out to our audience?

Dr. Nathan Smith: I guess we should keep an eye on some of these massive stars, because if some of these close by ones do go off, they're going to be spectacular events. If they're in the northern hemisphere, there are a few of these objects we've discovered if they do explode as supernovae, they'll be the brightest thing we've seen in a long time, so it's something to keep a look out for.

Pamela: But we here on Earth are in absolutely no danger, because they're all more than the *n* parsecs that you have to worry about.

Dr. Nathan Smith: I wouldn't say that necessarily. Eta Carinae is only 2 kilo-parsecs away, and if it were to explode in a very energetic supernova, something like a hypernova, we're probably going to be safe. Likely what would happen is that the x-ray blast from the supernova might disable all of our satellites. This happened recently with some coronal mass ejections from the sun, and if some satellites were disrupted with x-rays, this explosion would actually have a serious effect on our communications. If we were unlucky enough to have the pole of the star aimed at us in a gamma-ray burst or type event, some people have suggested that type of event may periodically cause mass extinctions on Earth. Whether or not that's true is debatable and luckily though it looks like Eta Carinae's pole is not aimed at us, so we're probably safe.

Pamela: So, humans are safe. Our atmosphere protects us from the UV, but lord help all the satellites in orbit?

[laughter]

Dr. Nathan Smith: Something like that, yeah

Pamela: Thanks a lot, Nathan. It's been great talking with you.

Dr. Nathan Smith: Great, thanks.

Fraser: Okay, great work Pamela! Thanks for getting out there and putting the microphone in people's face and getting the research right from them.

Pamela: It was my pleasure. It's really fun to get to talk to people about what they're doing, instead of just reading what they're doing in journal articles.

Fraser: Now next week, as we kind of threatened a couple of weeks ago, we're going to do the repercussions of the black hole episode. As predicted, our mailbox is filled up with questions about black holes, both clarifications and what-if's. I think we'll try and queue up a bunch of those for next week and get through them. You ready for that?

Pamela: I'm going to try and be ready for that!

Fraser: There are some pretty interesting questions

[laughter]

Fraser: Black holes always make people scratch their heads, so that will be good.

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Alright, thanks Pamela, we'll talk to you next week.

Pamela: Okay, see you later Fraser.

This has been Astronomy Cast, a weekly facts based journey through the cosmos. Music provided by Travis Searle.

This transcript has been edited to improve clarity..